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Session A4- New turbulence parameter for fish passage habitat

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Savage, Bruce and Coray, Chris, "Session A4- New turbulence parameter for fish passage habitat" (2011). *International Conference on Engineering and Ecohydrology for Fish Passage*. 9.
https://scholarworks.umass.edu/fishpassage_conference/2011/June28/9

New turbulence parameter for fish passage/habitat

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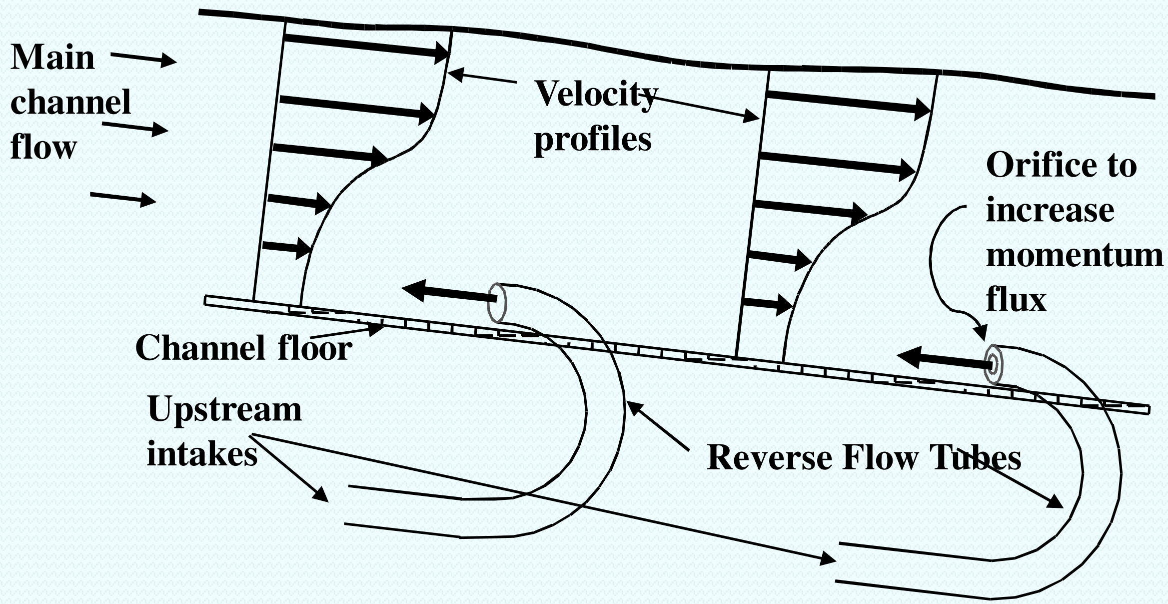
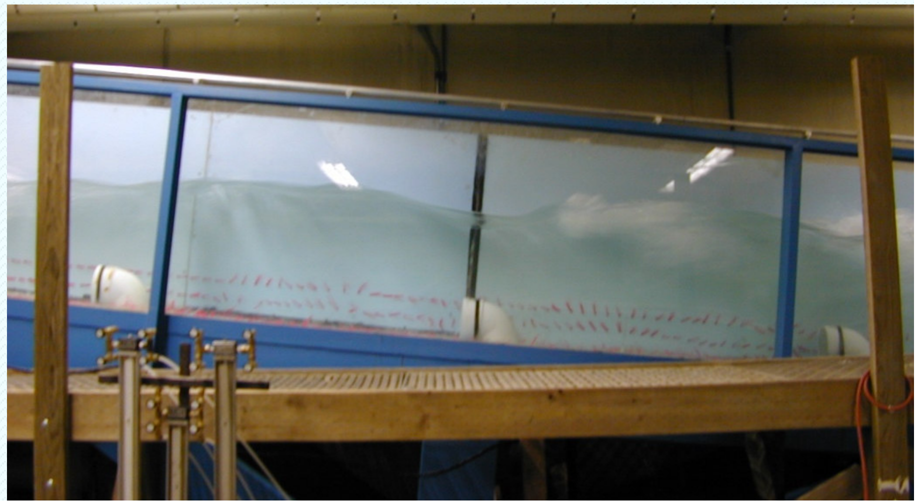
Background

Reverse Flow Tubes for fish passage - turbulence parameters didn't adequately describe flow.





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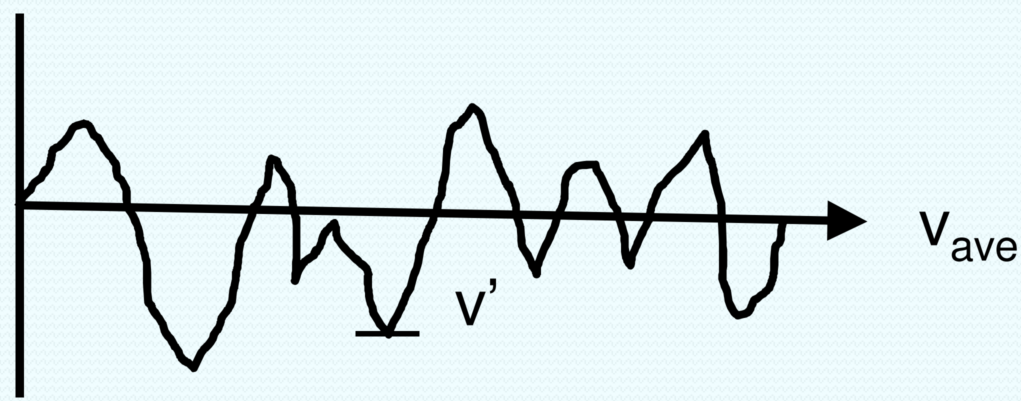
Turbulence - What is it?

- British physicist Sir Horace Lamb once said: "I am an old man now, and when I die and go to heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics, and the other is the turbulent motion of fluids. And about the former I am rather optimistic."

- In fluid flow, turbulence is simply defined as random velocity fluctuations



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Turbulence - Further Defined

Additionally, the following parameters can be used to further describe turbulence.

- Three-dimensional vortices
- Random orientation in space
- Rotational
- Stochastic (described by statistical terms)
- Diffusive (a marked particle wanders away from the average direction of flow and on average doesn't return

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Turbulence - Further Defined

Turbulence is often quantified by:

- Size of the vortices (characteristic lengthen or turbulence scale/length)
- Vorticity (rotational velocity), ω

$\omega = \nabla$ **x** velocity = curl of velocity

- Strength: vorticity x cross-sectional area of flow

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Turbulence - Vortices

Turbulence Cascade

Big whirls have little whirls
which feed on their viscosity;
and little whirls have lesser whirls,
and so on to viscosity.

(Poem by Lewis F. Richardson)

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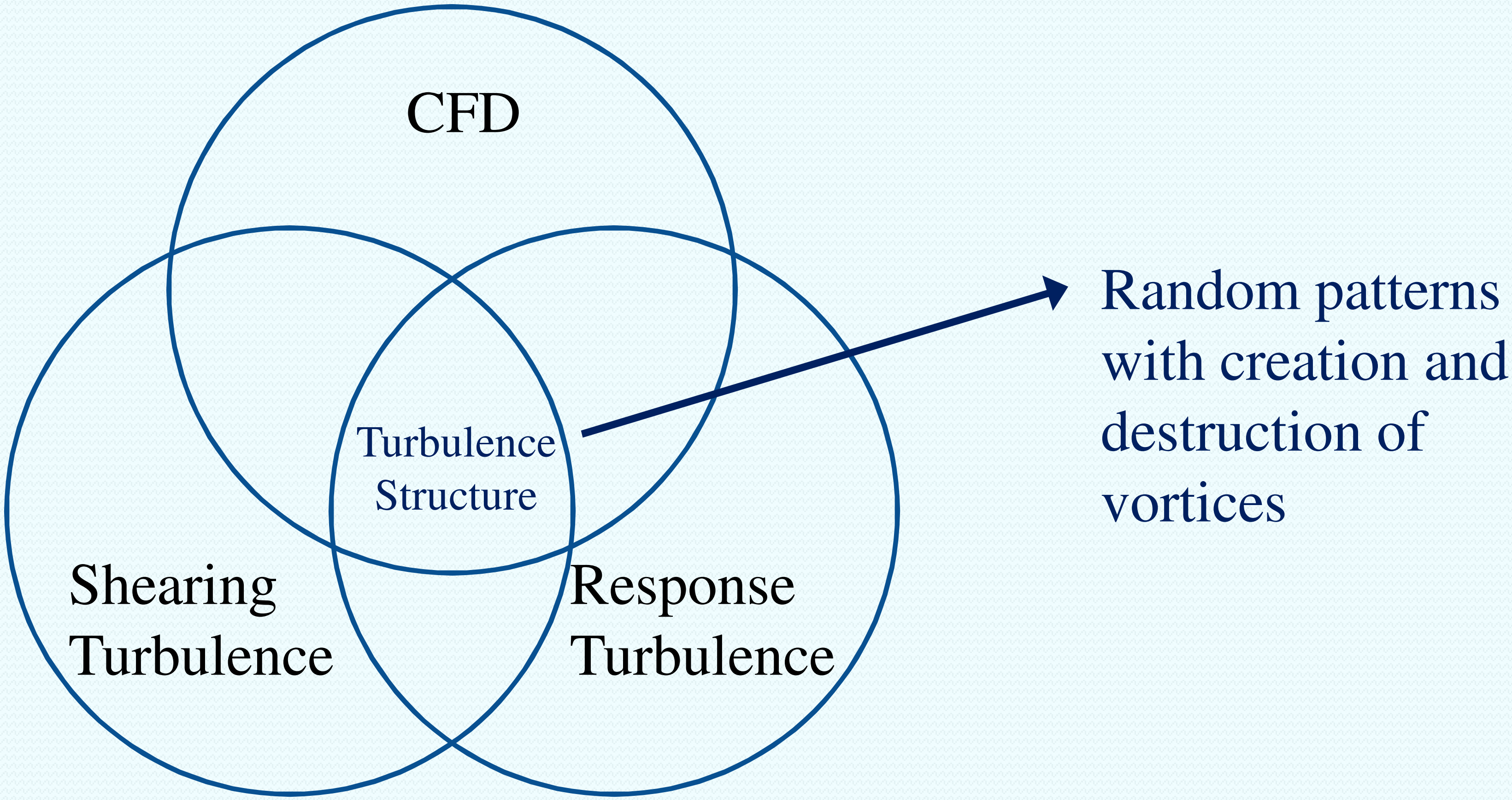
Classification of Turbulence



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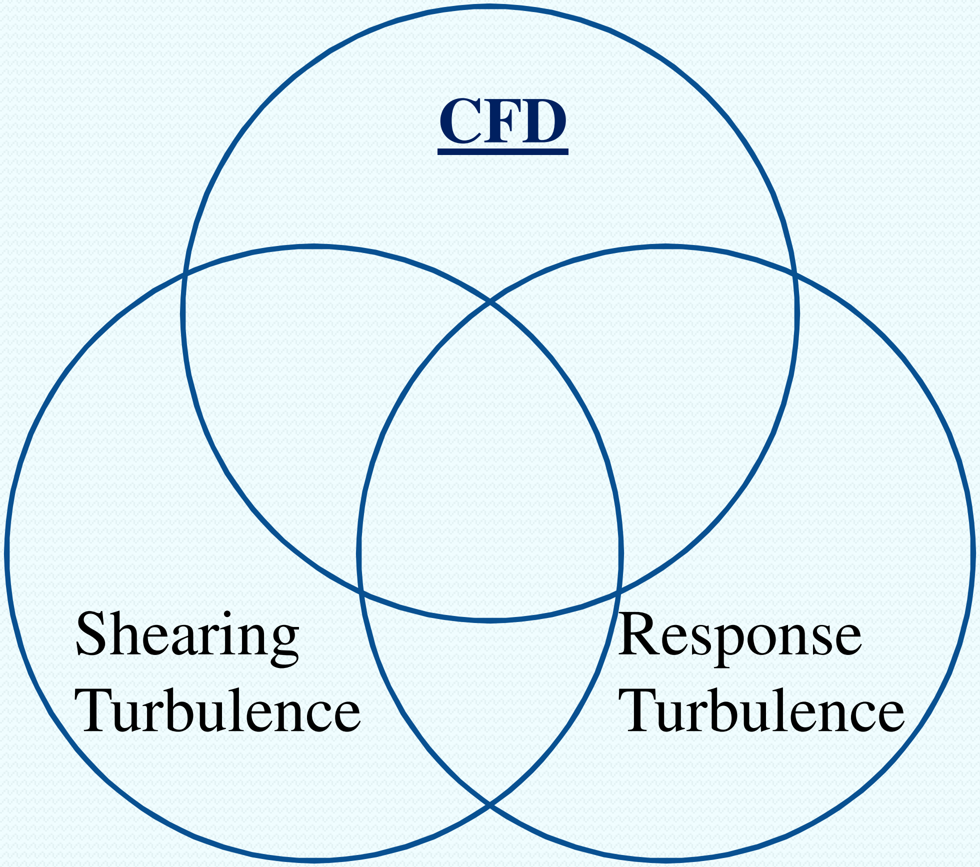
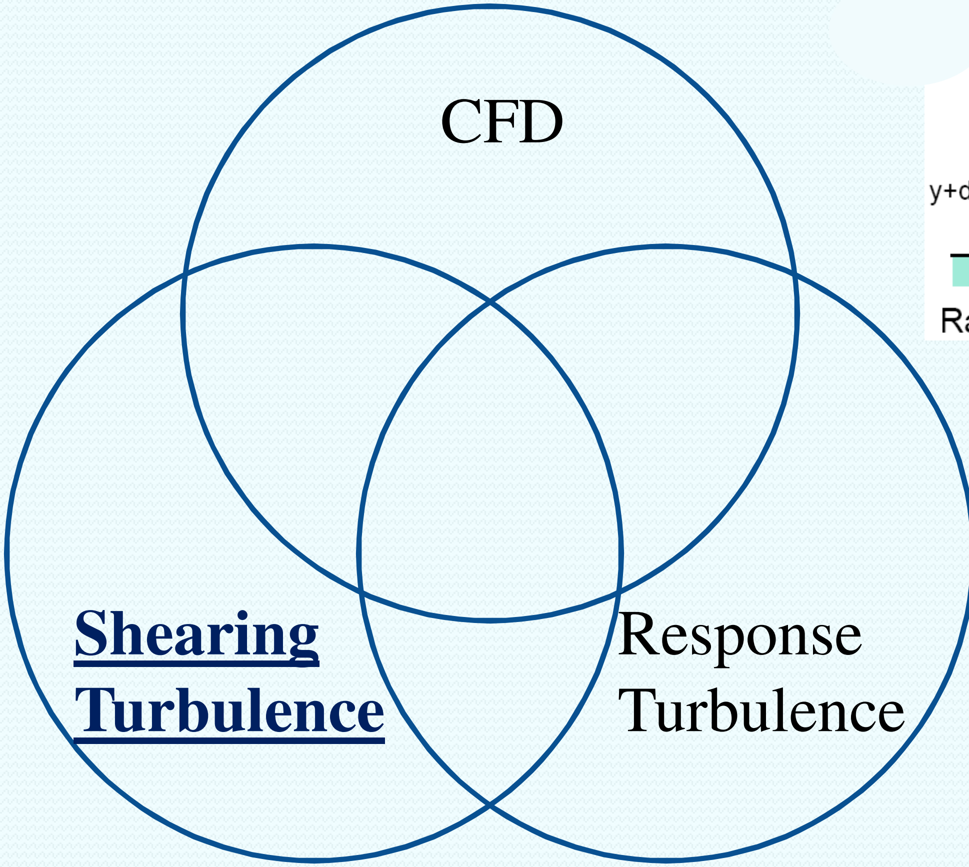
Classification of Turbulence

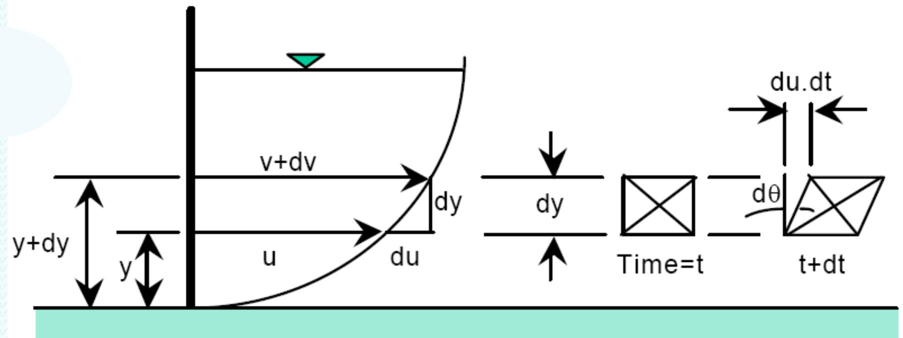


Characteristics

- Small scale relative to overall flow field (at sub-grid level)
- RANS and Turbulence Closure
- Defined time step (dt)

Classification of Turbulence



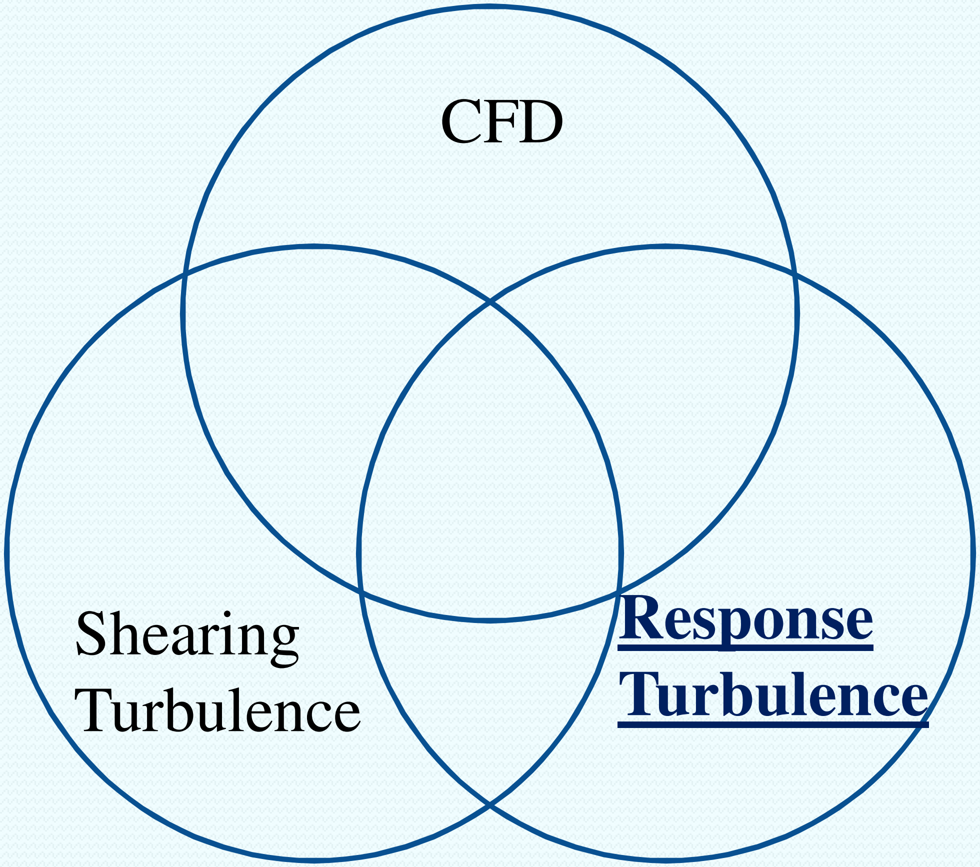


Rate of strain of a fluid element due to effects of viscosity

Characteristics

- High strength
- Controls movement of fish
- May damage fish

Classification of Turbulence



Characteristics

- Large and small vortices that elicits a response from fish (pressure and acceleration/deceleration)
- Detected through lateral lines/inner ear.
- May evoke avoidance or attraction response

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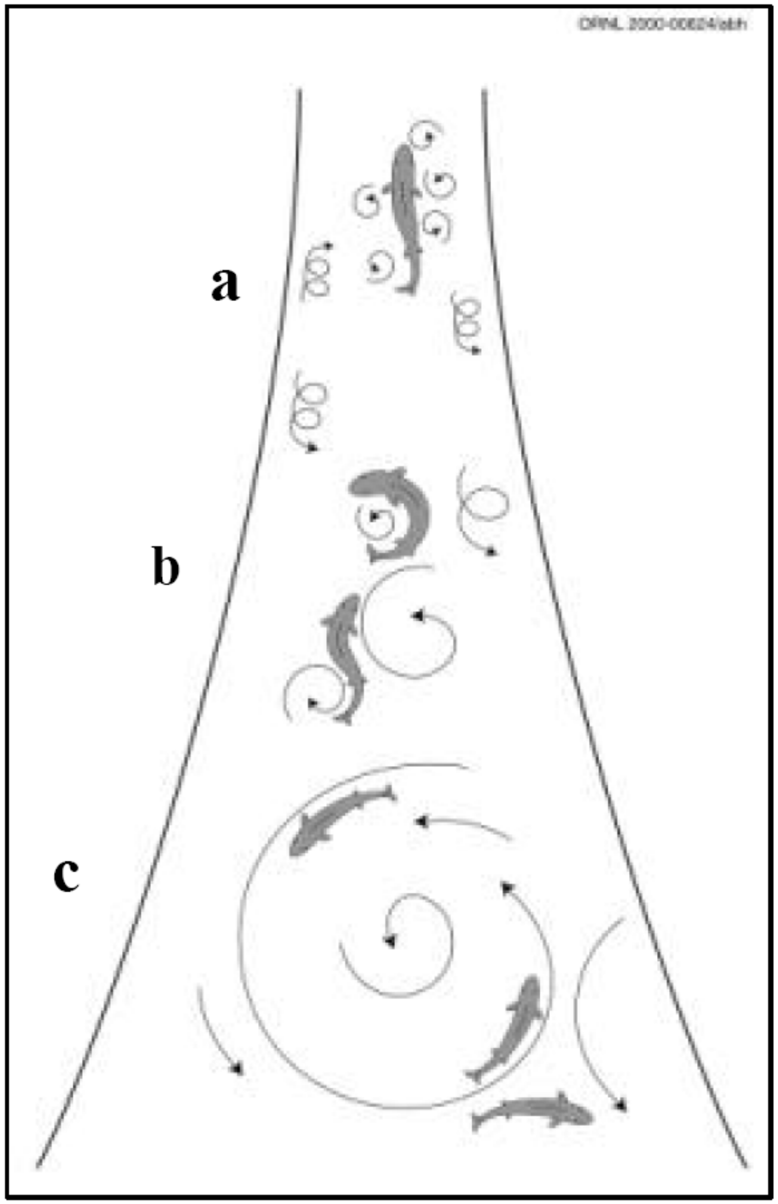
Scale of Vortices



Source: Odeh,2002

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Energy Dissipation Factor (EDF)

Generally applied to a fishways with a given head drop between pools.

$$EDF = \frac{\gamma Q \Delta h}{\forall}$$

Where

γ: specific weight

Q: flow rate

Δh: head drop

$\forall$: volume of pool

Root Mean Square (RMS)

Given a set of n-values, RMS = square of the mean sum of the squares

Usually applied to velocity fluctuations (perturbations), v'

$$RMS\left[v_i^{'}\right] = \sqrt{\overline{\left(v_i^{'}\right)}}$$

$$= \sqrt{\frac{\sum_{i=1}^{n} v_i^{'2}}{n}}$$

$$= \sqrt{\frac{\sum_{i=1}^{n} \left(\overline{v} - v_i\right)^2}{n}}$$

$$= \sqrt{\frac{n\sum_{i=1}^{n} v_i^2 - \left(\sum_{i=1}^{n} v_i\right)^2}{n^2}}$$

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Turbulence Intensity

$$T_i = \frac{RMS\left[v_i^{'}\right]}{U_{ref}} x\ 100 \quad \text{where } U_{ref} \text{ is a reference velocity}$$

Note: if k (kinetic energy per unit mass) is given as:

$$k = \frac{1}{2}\left(\overline{u^{'2}} + \overline{v^{'2}} + \overline{w^{'2}}\right) \qquad \text{then}$$

$$T_i = \frac{\left(\frac{2}{3}k\right)^{\frac{1}{2}}}{U_{ref}} x\ 100$$

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RMS/Turbulence Intensity Limitations

Given velocity samples:

	Smooth	Pulsing 1	Pulsing 2
Sample Velocities	-3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.5 1.0 1.5 2.0 2.5 3.0	-3.0 0.5 -2.5 1.0 -2.0 1.5 -1.5 2.0 -1.0 2.5 -0.5 3.0	-3.0 3.0 -2.5 2.5 -2.0 2.0 -1.5 1.5 -1.0 1.0 -0.5 0.5
Average	0	0	0
RMS	1.95	1.95	1.95
Skewness	0	0	0
Kurtosis	-1.41	-1.41	-1.41

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Turbulence Parameter

Goal: define a measurement that more accurately indicates conditions in the flow field

- Easy to measure in the field
- Evaluates turbulence from a fishes perspective
- Contained within the “response turbulence” region
- Captures much of the three-dimensionality, rotational, random and diffusive pattern of turbulence

Three-axis Method

Change in velocity = acceleration/deceleration

Given a velocity vector, $\vec{V} = V(x, y, z, t)$

Full derivative

$$\frac{D\vec{V}}{Dt} = \frac{\partial \vec{V}}{\partial t}\frac{dt}{dt} + \frac{\partial \vec{V}}{\partial x}\frac{dx}{dt} + \frac{\partial \vec{V}}{\partial y}\frac{dy}{dt} + \frac{\partial \vec{V}}{\partial z}\frac{dz}{dt}$$

$$= \underbrace{\frac{\partial \vec{V}}{\partial t}}_{\text{local derivative}} \underbrace{+ u\frac{\partial \vec{V}}{\partial x} + v\frac{\partial \vec{V}}{\partial y} + w\frac{\partial \vec{V}}{\partial z}}_{\text{material derivative}}$$

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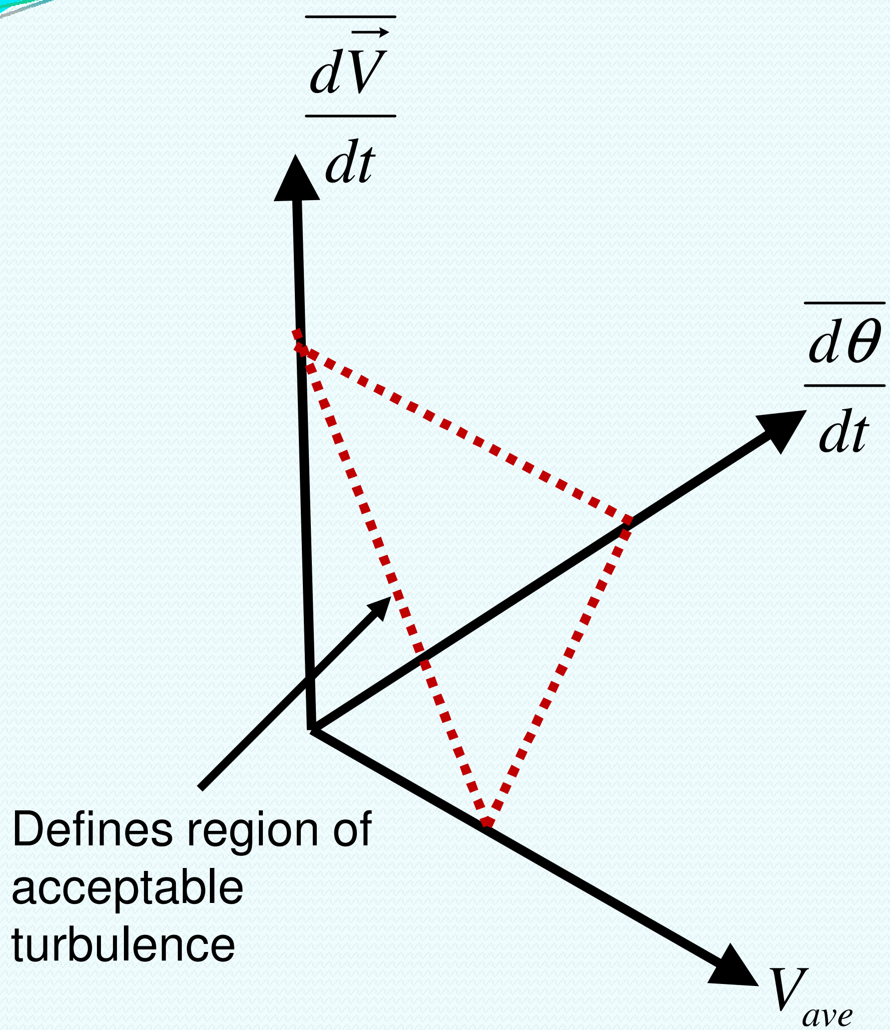
Three-axis Method



Incorporates:

- Local accelerations/ decelerations
- Strengthen based on average resultant velocity
- Rotation based on change in angle

$$\theta_{1-2} = a\cos\left(\frac{\vec{V}_1 \bullet \vec{V}_2}{\left|\vec{V}_1\right|\left|\vec{V}_2\right|}\right)$$

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Average Vector Method

Simplify:

- Strength: Average velocity resultant magnitude

$$\mathrm{V}_{\mathrm{ave}} = \frac{(V_1 + V_2)}{2}$$

- Acceleration: $a = \dfrac{(V_2 - V_1)}{dt}$ also $\mathrm{V}_{\mathrm{ave}} = V_1 + \left(\dfrac{1}{2}a\right)dt$

substitution gives

$$\mathrm{V}_{\mathrm{ave}} = \frac{(V_1 + V_2)}{2}$$

- Rotation: $\dfrac{d\theta}{dt}$

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Average Vector Method (T_f)

Combine:

- $$T_f = \left(\frac{V_1 + V_2}{2}\right)\frac{d\theta}{dt} = V_{ave}\frac{d\theta}{dt}$$
- Statistics: mean, standard deviation, skew, kurtosis
- Units: $\frac{L}{t^2}$ i.e. dimensions $\left(\frac{\text{ft}}{\text{s}^2}, \frac{\text{m}}{\text{s}^2}\right)$
- Newton's 2nd Law: F = ma

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Conclusion

- Turbulence is complex
- EDF and RMS leave out valuable information
- Three-axis method is instructive but hard to apply
- Average Vector method combines velocity magnitude, acceleration and rotation
- Actual data is required to further evaluate the Average Vector method

Collaboration

- Currently looking for collaborator(s) who would like to team up to test the concept. Specifically:
  - Biologists who can provide insight on delta t (response time of fish).
  - Field application. If you have a field test site where the concept can be applied as a comparison with other methods.
  - Create a team to write proposals/get additional funding to further test the concept.

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Classification of Vortices

THANK YOU

QUESTIONS/COMMENTS

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